Section 2

PROJECT SUPPORT ACTIVITIES

Excellence in the selection, evaluation, and acquisition of reliable microelectronics for space applications based on the latest technical knowledge, superior laboratory capabilities, efficient and cost effective processes, and commitment to customer service.

EPE Vision Statement

Overview

Providing direct JPL flight project support is the prime function of the Electronic Parts Engineering Office. In fiscal year (FY) 2002, the office was heavily involved in the engineering, test, characterization and acquisition in support of 26 JPL projects and instruments. In response to evolving project needs, the office has had to re-plan a number of activities to accommodate additional un-forecasted needs or in response to specific technical problems encountered during the normal course of activities. In our efforts to provide the necessary support of our projects, we utilized standard parts program requirements and practices. The suitability of the parts program requirements and related workforce plans were reviewed by the Parts Review Board (PRB), which provided a more consistent approach from the office and addressed the project risk profile.

The responsible project interface engineers (PIE) provided a single point of contact for their project with the Electronic Parts Engineering Office. The coordination of all the part reviews and associated test and characterization or acquisition tasks was integral to the section' s ability to provide the project with the necessary support. In FY2002, the Electronic Parts Engineering Office provided 26 Total Ionizing Dose radiation tests, 15 Single Event Effects radiation tests, 110 Destructive Physical Analyses, 10 Failure Analyses, 5 Construction Analyses, and over 75 parts screening tests and various other evaluation and characterization activities.

The Mars Exploration Rover (MER) project was one of the larger projects in the office, consuming more than 30% of available workforce. The office was successful in providing acquisition services to procure over 4000 electronic parts to satisfy a very aggressive schedule and a continually evolving design. Twenty-six radiation tests were performed to evaluate the suitability of various parts types and characterize their performance under the specified project environment. A considerable amount of inherited flight subsystem hardware required detail part list review and evaluation. This resulted in 127 Non-Standard Part Approval Request (NSPAR) and 163 parts waivers. In addition, 190 Destructive Physical Analyses (DPA) were performed; 84 in-house and 106 outsourced. About 15 plastic encapsulated microcircuits (PEM) were up-screened for non-critical circuit applications.

An interesting outcome of this activity was that the fallout or failures from the up-screen of PEM devices, even under extreme temperature conditions, was much lower than anticipated. A detailed analysis of the results of these and other tests will provide a better understanding of the suitability of such products for space applications.

In support of the X2000 project, we accomplished meeting the project' s needs for conducting parts reliability evaluation and radiation tests. We had a number of engineers dedicated to the project so that they could work closely with design engineers and contractors to resolve parts reliability issues and problems. As a result, we now have a better understanding of single event radiation sensitivities of synchronous dynamic random access memory (SDRAM), voltage regulators, and RAD750 flight computers.

Finally, we delivered the last electronic parts required to Cloudsat, prepared qualification plans for various components on Herschel-Planck, and will begin performing the qualification testing soon. The Mars Reconnaissance Orbiter (MRO) project has been quite active; we have received many NSPARS on inherited hardware. The Electra transceiver design team has been very proactive, writing NSPARS and waivers and pushing for approval early. The Ocean Surface Topography Mission (OSTM) got started and we were asked to provide support for the instruments only. We have identified long-lead items in the parts list and established price and delivery schedules. The parts lists for two of the key instruments were successfully completed and the results were presented to the project.

Because we are the focal point for the project parts support activities, we had opportunities to conduct numerous reliability evaluations, characterizations, and qualification testing for various devices. The following is a brief description of some examples of project support activities.

Examples of Project Support Activities

Enhanced Low Dose Rate

High- and low-dose rate radiation tests were conducted on precision voltage reference, LT1019, for the MER project. Though the MER dose requirement was only 5 krad(Si). Testing was extended to 30 krad(Si) to make the device useful for more applications and show where the device exceeded specification limits. By performing the extended testing, the device was found to exhibit enhanced low-dose rate sensitivity (ELDRS) with the biased low rate case being the worst. The results are shown in Figure 2-1. This performance was not completely expected since previous tests of the similar device from the same manufacturer showed no such dose rate dependence. Without the extended testing this effect would not have been found.

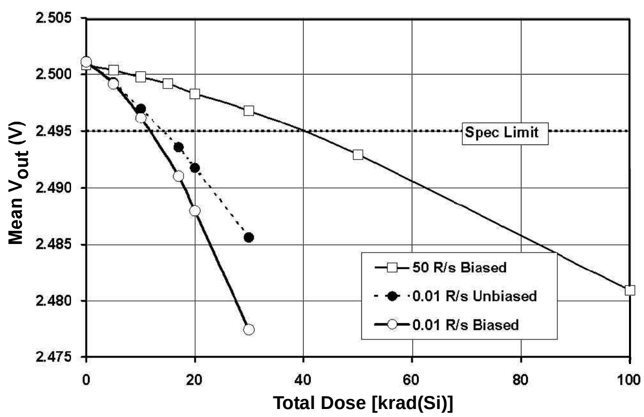

Figure 2-1. LT1019 - 2.5 Voutput, comparison of total dose test results at different dose rates and bias conditions

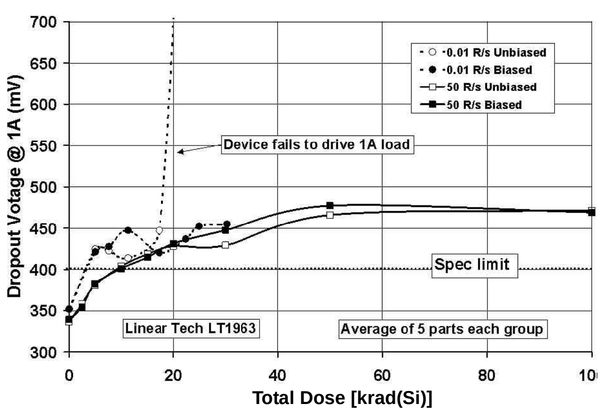

Figure 2-2. LT1963 dropout voltage measurements during total dose test with various dose rates and bias conditions

Additionally, a voltage regulator, LT1963, was also tested at high and low dose rate for the MER project. The results are plotted in Figure 2-2. In this case, no significant bias or dose rate sensitivity was found at the project required dose levels. After 15 krad(Si), however, the device went non-functional for the unbiased low rate case alone. This example shows the importance of doing biased and unbiased testing up to device failure levels.

FPGA Failure Analysis Investigation

Over 60 RT54SX32-S FPGAs were used to implement 16 designs for the MER spacecraft avionics. The devices were procured blank (i.e., unprogrammed) and programmed with the JPL-supplied designs, screened for electrical and functional performance, dynamically burned-in and screened again post burn-in. During the post burn-in screening, anomalies were measured in six of the devices. We investigated the anomalies to determine if the devices already installed in the MER hardware exhibited any reliability concerns for the mission.

Failure Analysis was performed to review the electrical parameters of the set of 60 parts screened at a contractor site, the electrical design and performance of the burn-in boards, the cause and/or nature of the observed anomalies at the device level, and the acceptability of the parts for use in the MER mission. A review of the electrical parameters measured showed that the performance of the parts was tightly grouped statistically and well below the manufacturer specifications, except for the six anomalous parts.

A review of the electrical design and performance of the burn-in boards showed that although the board design omitted bypass capacitors for the supply voltages, the transient voltage levels were not likely to have electrically overstressed the parts. Measurements showed that the six anomalous parts were indicating degradation prior to burn-in and the post-programming burn-in was effective in flushing out the failed parts. A life test was conducted at +125°C for 1000 hours using 3 of the anomalous parts in one test setup and 3 other parts from the flight lot in the other test setup. The results showed no device degradation, produced data comparable to a previous lifetest done by the manufacturer on devices from this same lot, and demonstrated a lifetime greater than 7 years (more than 6 times the mission lifetime.

Tin Whisker and Actuator Motor Evaluation

Chip capacitors with pure tin terminations were installed in flight assemblies of the Small Deep Space Transponder (SDST), despite a ban on the use of components with pure tin leads. Pure tin leads are banned because small filament-like structures (whiskers) grow from the surface of the tin, and can potentially break loose from the surface and deposit elsewhere within the component, as shown in Figure 2-3. If the length of the whiskers is comparable to the spacing between conductors, a whisker can bridge conducting elements and cause a short, as shown in Figure 2-4.

Since rework entailed a risk of damage to the assembly, it was decided to measure the rate of whisker growth and assess the risk for MER for this particular set of terminations, pure tin over a nickel barrier. Based on the rate of whisker growth during a 3-Mission lifetime set of thermal cycles, it was found that no significant risk existed for this set of capacitors for the MER project lifetime, and rework was avoided. In addition to resolution of the MER SDST problem, the study uncovered previously unknown facts about whisker growth, such as the dependence of whisker growth on passage through a tin phase transformation, which will aid in assessing any future tin whisker occurrences. The findings were documented a report titled " WB514013: Tin Whisker Issues for MER" by S. D' Agostino and W. Bozse, July 2002.

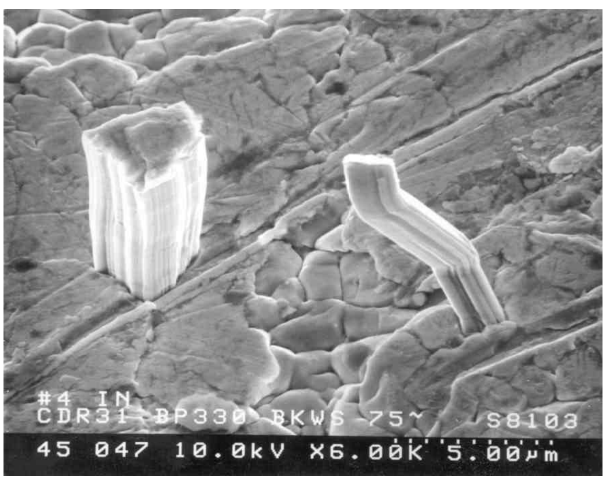

Figure 2-3. SEM photo of tin whiskers. Pillar is approximately 5 µm and the kinked whisker approximately 8 µm total.

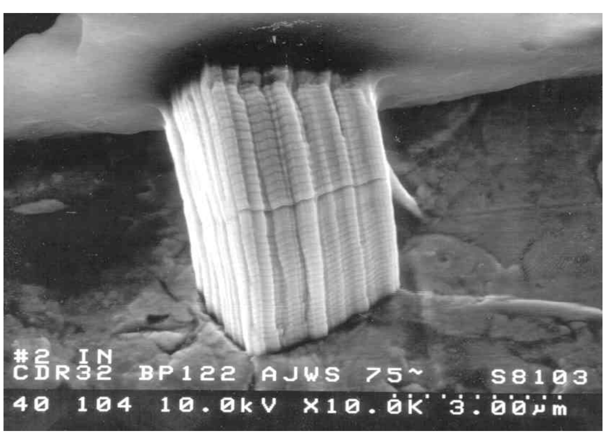

Figure 2-4. Tin whisker (about 8 µm) lifting a contaminate patch off the tin plating surface.

New Millennium Program (NMP) Assessment

An electronic parts reliability assessment was completed for The New Millennium Program (NMP) Office for the effects of space environments on electronic components. This can be used to aid NMP proposal selection and mission design processes, and to educate NMP participants about the relevant risks in hostile environments. Electronic devices were categorized by technology. Existing experimental data were used to assess technology-specific performance under radiation, thermal, electrostatic and vibration environments.

One of the most important issues was to address thermal environments for electronic devices. Devices are usually enclosed in a controlled thermal environment in the spacecraft interior, provided by a high-thermal capacity base plate. The base plate temperature is determined by the external heat absorbed by the spacecraft and the heat generated by the functioning electronic components, and is regulated by passive heat distribution and active heating elements.

The typical device performance per technology is shown in Table 2-1. It should be stressed that the table is less representative of the technology itself, but it reflects the degree of complexity of the typical devices. For example, extremely low temperatures do not impede complementary metal-oxide semiconductor (CMOS) technology itself, but complex CMOS devices can lose functionality due to loss of drive current and timing correlation among operations.

In addition, the thermal characterization tests can vary significantly depending on the use of devices, and not only on the device type and technology. For example, a deviation of a functional parameter resulting from extreme temperature may be critical in one application, and unimportant in another.

Table 2-1. Typical performance of electronic device technologies in thermal environments

		Thermal Environments					
		Orbiter / Deep Space		Lander / Probe			
				Mars		Venus	Europa
		Interior (- 10°C/+50°C)	Exterior (- 120°C/+150°C)	Interior (- 10°C/+50°C)	Exterior (-125°C/+25°C)	+475°C	- 145°C
CMOS	Linear	Green	Orange	Orange	Orange	Red	Orange
CMOS	Analog RF	Green	Orange	Orange	Orange	Red	Orange
CMOS	Mixed Signal	Green	Orange	Orange	Orange	Red	Orange
CMOS	Digital Logic	Green	Yellow	Yellow	Orange	Red	Orange
CMOS	Flash Memory	Green	Yellow	Yellow	Orange	Red	Orange
CMOS	Processors	Green	Yellow	Yellow	Orange	Red	Orange
BiCMOS Linear		Green	Orange	Orange	Orange	Red	Orange
Bipolar	Complement	Green	Yellow	Yellow	Orange	Red	Orange
Bipolar	Linear	Green	Orange	Orange	Orange	Red	Orange
Bipolar	Digital	Green	Yellow	Yellow	Orange	Red	Orange
MOSFET		Green	Yellow	Yellow	Orange	Red	Orange
JFET		Green	Orange	Orange	Orange	Red	Orange
BJT	Power	Green	Yellow	Yellow	Orange	Red	Orange
BJT	Signal	Green	Yellow	Yellow	Orange	Red	Orange
SOI		Green	Yellow	Yellow	Orange	Red	Orange
SiGe		Green	Yellow	Yellow	Orange	Red	Orange
III-V Electr.	SRAM	Green	Green	Green	Green	Red	Green
III-V Electr.	RF	Green	Green	Green	Green	Red	Green
III-V El.-Opt.	Laser, LED	Green	Yellow	Yellow	Yellow	Red	Yellow
III-V El.-Opt.	Detect, solar cell	Green	Yellow	Yellow	Yellow	Red	Yellow

Legend:
MOSFET = metal-oxide field-effect transistor
JFET = junction field-effect transistor
BJT = bipolar junction transistor
SOI = silicon on insulator
SRAM = static random access memory
Green = major effects unlikely
Yellow = failures possible, assessment needed
Orange = undefined performance, special measures may be required
Red = special measures required

Herschel/Planck Qualifications

Herschel is an orbiting infrared telescope that will take high-resolution images in the submillimeter and far-infrared regions of the electromagnetic spectrum. These images will help explain how stars and planetary systems form. It will be the only space facility ever developed covering the far infrared to submillimeter range of the spectrum (from 80 to 670 micrometers). It will open up a virtually unexplored part of the spectrum which cannot be observed well from the ground.

The work in support of this project consisted of the preparation of space qualification plans in support of the Herschel Space telescope. Plans consisted of a list of tests, acceptance criteria and other requirements and were prepared for Superconducting-Insulating-Superconducting (SIS) tunnel junction, hot electron bolometers (HEB), GaAs power varactors, and GaAs multipliers.

Qualification challenges included the need to address unknown failure mechanisms observed in GaAs varactors (Schottky diodes used in multiplier chains. These varactor circuits have been developed for broadband frequency multipliers to cover the frequency range from 200 GHz to 1900 GHz. Each local oscillator (LO) chain consists of two to four frequency multipliers in which each varactor presents a single point failure for that particular LO chain. A better understanding of how and why varactor diodes fail is thus imperative for successful implementation.

Additional challenges included testing and qualification of commercial off-the-shelf components with unknown cryogenic performance but that are integral parts of some of the circuits in the Herschel instrumentation. Further concerns are the unknown effects of radiation (the L2 orbit does encounter proton fluxes and it is expected to see some displacement damage causing radiation over the three years Herschel is expected to be in operation) and the effects of humidity on very delicate hot electron bolometers and Superconductor insulator superconductor junctions during the pre-launch time period. Additional challenges stem from the novelty of these bolometers, which are being developed specially for this purpose at JPL. The device design and materials for some of these advanced bolometers are still in evolution, which makes qualification particularly challenging.

These plans focus on qualification issues at cryogenic temperatures. This support work also includes experimental support and data analysis for humidity testing in HEB, which show extreme sensitivity to humid conditions. This effort involved working with device engineer to design qualification testing tailored to the various devices and systems to be qualified.

Latchup Tests of the DSP2100 Digital Signal Processor

The Microwave Limb Sounder (MLS) project uses a DSP2100 signal processor to control three different subsystems within the instrument. This part is sensitive to latchup with ions that have relatively low linear energy transfer (LET). Furthermore, the latchup is destructive unless special measures are used to turn off the latchup condition shortly after latchup occurs. Unfortunately, the project was unaware of the destructive nature of the latchup until well after the hardware and software for the instrument was developed. Office 514 performed a number of special tests to evaluate the latchup characteristics of the DSP2100 in more detail, with the goal of determining how a combination of hardware and software detection methods could be used to decrease the probability of destructive damage from latchup. The result is that the probability of destructive latchup has been reduced by more than a factor of three with the hardware and software latchup detection methods in place. Although there is still a finite probability for latchup, the net probability of destructive latchup in the MLS system has been reduced to one event in ten years, which is acceptable to the project.

Initial tests at two different accelerator facilities characterized the dependence of latchup on LET, which then allowed the probability of latchup to be determined. These tests are documented in " Single-Event Effects Test for the First Five Part Types Used on the MLS Program," F. Irom et al., May 2001.

Subsequent tests in a laboratory at JPL using californium-252 demonstrated that destructive latchup could be avoided by shutting down high-current latchup events within 1 ms, and lower current latchup events within 400 ms. Those time profiles were established by the MLS project in anticipation of the times that would be implemented by hardware and software detection methods. These tests are documented in a report, " Study of Catastrophic Latchup in the DSP2100 Signal Processor Chip for MLS," by H. Becker et al.

To test a " breadboard" system, we had to use the DSP2100 and all related circuitry, at a particle accelerator. A special hardware detection circuit designed to shut down high-current latchup events within 1 ms was used in series with the 5-V power system that controlled the system, along with a developmental version of the software approach that will be implemented to detect lower current latchup events. The results of this test showed that the hardware detection method worked reliably, but that the software approach was not completely successful. Nevertheless, the tests verify that the combination of the software and hardware latchup detection methods will reduce the probability of latchup from heavy ions to an acceptable level for the project. These tests are documented in " Heavy-Ion Test of the Latchup Mitigation Circuit for the DSP2100 Digital Signal Processor Used on MLS," G.M. Swift et al., September 2002.

Recovery of Radiation Damage to the Galileo Tape Recorder

The tape recorder used on Galileo failed during the 34th orbit near Jupiter. That particular orbit extended more deeply into the Jupiter radiation belts, exposing the tape recorder to a much higher incremental exposure to protons compared to the previous 33 orbits. The Galileo team used the status signals from the malfunctioning recorder to determine that the reason for the operational problem was failure of an LED/phototransistor pair that was used to control tape-recorder operation.

Initially, the Galileo team proposed heating the spacecraft, assuming that relatively small temperature increases would cause some of the damage to anneal. The Radiation Effects Group provided technical information that showed (a) annealing was negligible unless temperatures above 150 degrees Centrigrade could be achieved, and (b) that damage in the LED was the main contributor to failure. Furthermore, previous work done to support optocoupler failures on TOPEX/Poseidon showed that about 1/3 of the damage could be annealed by passing a steady current through the device for extended time periods (current-enhanced annealing). The Galileo team devised a scheme to put the LED in a steady-state mode, with a current of 22 mA (about 25% of the maximum rated current). After 100 hours, the LED recovered sufficiently to restore tape recorder operation.

Power Converters

An investigation of total dose effects in power converters was started in FY02 because of unexpected catastrophic failures in hardened power converters that occurred at a level approximately 20 times lower than the hardness level guaranteed by the manufacturer. The problem was identified about 3 months before the launch of two spacecraft, and was a critical issue. The Radiation Effects Group demonstrated that the failure was caused by an unusual response mechanism in a CMOS digital part that was used within the converter. An extensive series of tests was done, including tests at low dose rate, along with selected irradiations of different components within the (hybrid) converter with X-rays. The results showed that although the converters failed below the expected failure level, they still operated satisfactorily for the two missions that used them. The manufacturer has since changed the design to remove the particular component that caused the problem. The results of these tests were published in a paper "Low Dose Failures of Hardened DC-DC Power Converters," J. Lehman et al., IEEE 2002 Radiation Effects Data Workshop, pp. 109-114.

Catastrophic Damage in Power MOSFETs

One JPL project required power MOSFETs with extremely high voltage ratings (> 500 V). Radiation tests on these devices showed that the test results depended very strongly on the range of the ions that were used during testing. Unless ions with very long range were used, the allowable operating conditions to avoid gate rupture were far too optimistic. Figure 2-5 compares test results from the manufacturer, with ions that have only a limited range, with JPL test results for long-range ions. The lightly doped region under these high-voltage devices is about 130 micrometers deep, which is the reason for the requirement for very long range.

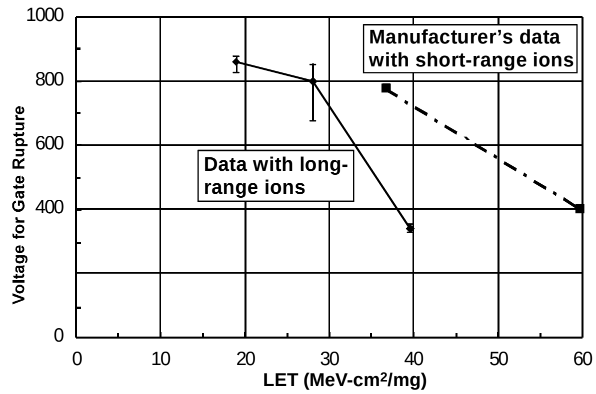

Figure 2-5. Single-event gate rupture (SEGR) test results on International Rectifier (IR) 1000 V power MOSFET